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THE LIFE HISTORY OF THE TWISTED WIREWORM (Hæmonchus contortus) OF SHEEP AND OTHER RUMINANTS.

(Preliminary report.)

By B. H. RANSOM, B. Sc., A. M.,
Scientific Assistant in Charge of Zoological Laboratory.

In the course of investigations of the roundworm parasites of sheep now in progress in this laboratory certain facts have been determined which not only make plain the principal points in the life history of *Hæmonchus contortus*, the twisted wireworm of sheep and other ruminants, but also demonstrate a method of infection which from its nature is peculiarly adapted to the food habits of grass-eating animals, and will doubtless be found to apply to various other strongyloid worms of the herbivora. Although the investigations are yet in an unfinished state, it is believed that the importance of the facts referred to render a report desirable at the present time, though it must necessarily be rather brief and incomplete.

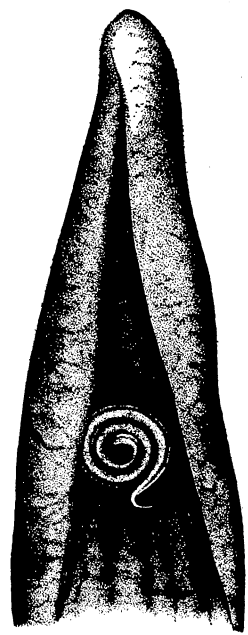

FIG. 1.—Embryo of *Hæmonchus contortus* coiled on tip of grass blade. Enlarged 100 times. Original.[1]

DEVELOPMENT OF THE EMBRYOS.

The eggs of *Hæmonchus contortus* as found in the fresh feces of an infested animal are in various stages of segmentation. Some of them in a culture of feces kept at a temperature of 16° to 20° C. hatched within two days, while others in the same culture did not hatch until a week had elapsed. The newly hatched embryo is of the common rhabditiform type, about 350 μ long, with a slender, acutely pointed tail. The embryos begin to feed almost immediately after hatching and grow very rapidly, attaining their limit of embryonic growth in a few days, then measuring from 650 μ to 820 μ in length. During this period of growth the skin is

[1] Figure 1 shows the tip of a grass blade bearing an embryo of *Hæmonchus contortus*, which during periods when the air was saturated with moisture had crawled up from the earth in which the grass was growing. At the time the drawing was made the amount of moisture in the atmosphere had fallen below the point of saturation, and the embryo, in consequence, had coiled itself together and become quiescent.

cast at least once, one embryo 600 μ long having been observed in the act of molting, and it seems not unlikely that a prior molt also occurs. Its growth completed, the embryo no longer feeds. The cells of the intestine have become laden with food granules, the pharynx has disappeared, the esophagus is no longer apparent, and a new cuticle has appeared inside the old. The mouth and anal openings in the outer cuticle have been sealed up, and the opening of the excretory pore seems also to be closed, so that the embryo is now incased in the former cuticle as in a sheath. At this stage the tail of the embryo proper is shorter and less slender than in previous stages and falls about 75 μ short of the posterior tip of the sheath. Practically all the embryos in feces which had stood from ten to fourteen days at a temperature of 16° to 20° C. were found to have reached the sheathed stage, and some arrived at this stage even earlier.

EFFECTS OF COLD AND DRYNESS.

Prior to this stage the embryos, as well as the unhatched eggs, showed but feeble vitality under adverse conditions and were speedily killed by drying. Exposure of eggs and newly hatched embryos to a freezing temperature for twenty-four hours also resulted fatally in a number of instances.

On the other hand, sheathed embryos proved resistant in a high degree both to cold and dryness. Worms in feces collected December 14 and placed outdoors December 27, 1905, were still alive when last examined (March 22, 1906) and became active in a few minutes after being brought into the laboratory. Furthermore, their supply of food granules had not appreciably diminished, while in embryos from the same collection which had been kept indoors continuously the food granules had almost entirely disappeared from the cells of the intestine. The maximum temperature outdoors during this period was 71° F., the minimum 7° F., the total number of hours during which the temperature was 30° or lower being 494, so that the embryos were in a frozen condition almost one-fourth of the entire time which elapsed from December 27 to March 22. On three different occasions they remained frozen continuously for over forty-eight hours, and they were frozen and thawed out thirty-two times.

The resistance of the sheathed embryos to dryness is no less striking. A small portion of a culture of feces collected December 14 was allowed to dry February 28 and thereafter left open to the air of the laboratory. During the course of this experiment nine determinations were made of the relative humidity of the air of the laboratory on five successive days, the average being 37 per cent, with a maximum of 48 per cent and a minimum of 25 per cent, showing that the air was very dry. Small quantities of these dried feces were taken from time to time and moistened. On April 4, the date of the last test, after thirty-five days in a

dried condition, the embryos in the feces were still alive and became active in a few hours after being moistened. The dried embryo is much shrunken within its sheath, no details of internal structure are visible, and it seems to be entirely lifeless, but under the influence of moisture it gradually resumes its normal appearance and movements and again fills out the cavity of the sheath.

If placed in a drop of water which is allowed to evaporate slowly, embryos usually coil themselves into a spiral as they become dry.

Placed in a vessel of water, they soon sink to the bottom and remain there, except as they may be carried upward by ascending currents. It seems impossible, or at least very difficult, for them to sustain themselves in water by their own efforts for any length of time, and in perfectly quiet water practically none can be found except at the bottom.

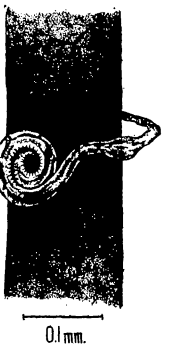

FIG. 2.—Embryo of *Hæmonchus contortus* in very dry condition on grass stalk. Enlarged 100 times. Original.[1]

One of the most interesting points which developed in the study of the embryos, when viewed in connection with their ability to resist dryness, is the facility with which they ascend perpendicular surfaces when the atmosphere is saturated with moisture. This fact is readily demonstrated by placing some moist earth containing sheathed embryos in the bottom of a wide-mouthed bottle, which is then corked to prevent evaporation. When the air in the bottle becomes saturated with moisture the worms begin to crawl in numbers up the sides of the bottle and can easily be seen with a hand lens. On a smooth glass surface in an atmosphere saturated with moisture the rate of upward progress in a number of instances observed was about 6 mm. (one-fourth inch) per hour. Blades of grass, at the roots of which was placed a culture rich in embryos, were swarming with the worms after remaining a few days in a saturated atmosphere under a bell jar.

MODE OF INFECTION.

The foregoing facts indicate the life history of *Hæmonchus contortus* to be essentially as follows:

The eggs of the parasite are scattered over the pastures in the feces of infested sheep or cattle. Under suitable conditions of heat and moisture they hatch in a few days, and within about two weeks the embryos reach the ensheathed stage. Thereafter, during wet weather

[1] Figure 2 shows a grass stalk bearing an embryo of *Hæmonchus contortus* in a very dry condition. This embryo is one which had crawled up the grass from the base of the stalk while in a saturated atmosphere under a bell jar. The dish in which the grass was growing was afterwards removed from under the bell jar and the grass allowed to die. The drawing was made after the grass had been in a dry condition, almost like hay, for three days. The embryo revived in a short time after being placed in water.

and on dewy nights, the embryos crawl up the grass stalks, ceasing their migrations when the humidity of the atmosphere falls below the point of saturation and when the dew evaporates. The movements of the worms are resumed or cease according to the presence or absence of dew or other moisture, and they gradually get higher and higher on the grass blades, reaching locations where their chances for being swallowed by grazing animals are proportionately increased. Infection, therefore, is apparently accomplished by means of grass which has become infested in the manner indicated.

EXPERIMENT WITH SHEEP.

In order to determine whether embryos in the stage during which they crawl up grass stalks are able, in accordance with the supposed mode of infection, to continue their development when swallowed by the proper host animal, the following experiment was performed:

Four sheep were confined in stanchions and dosed repeatedly with coal-tar creosote in 1 per cent solution in order to free them as far as possible from *Hæmonchus contortus*, with which, judging from fecal examinations, they all seemed to be infested to a slight degree. Two of these were drenched January 30, 1906, with a culture of feces collected December 14, 1905, and containing numerous embryos of *Hæmonchus contortus* in the ensheathed stage. Each of the two animals received in this way several thousand embryos. The other two animals were held as checks. On February 24, about three weeks later, one of the animals which had received the embryos and one of the checks were killed and the alimentary canal examined. In the fourth stomach of the check animal, the animal which fecal examination prior to the anthelmintic treatment had shown to be most heavily infested with worms, six adult worms of the species *Hæmonchus contortus* were found, evidently individuals which had escaped the action of the treatment. In the other animal no full-grown ovigerous worms could be found in the fourth stomach, but thousands of worms of the species *Hæmonchus contortus* were collected, none of which had yet arrived at the stage of active egg production. The two remaining animals were killed April 12, and the results of the examination were entirely in accordance with those obtained in the other case. The check animal had three adult worms of the species *Hæmonchus contortus* in the fourth stomach, while the fourth stomach of the animal which had received embryos January 30 contained several thousand adult worms of this species. It therefore seems safe to conclude, especially in view of the perfect correlation of the results of this experiment with the other facts which have been determined concerning the behavior of the embryos, that the embryo of *Hæmonchus contortus* when it has reached the sheathed stage is ready to complete its development to maturity when swallowed by a suitable host animal.

SUMMARY OF LIFE HISTORY.

The facts regarding the life history of *Hæmonchus contortus* and the resulting conclusions may be summarized as follows:

1. The embryos hatching from the eggs contained in the feces of infested animals reach the ensheathed stage at which they are ready to be taken into the body in from ten days to two weeks under suitable conditions of heat and moisture.

2. The eggs and newly hatched embryos possess little powers of resistance, and many die if subjected to freezing or drying. While further experiments in regard to this point are necessary, it seems probable that a large proportion of the eggs contained in feces passed by infested animals during freezing weather will fail to develop.

3. The ensheathed embryos, on the other hand, are highly resistant to both cold and dryness. Continued and repeated freezing has little or no effect upon them, and they will withstand for weeks at a time conditions of dryness fully as extreme as those to which they are commonly subjected in a state of nature.

4. Embryos hatching in feces collected December 14, 1905, were still alive March 22, 1906, with no apparent reduction in activity. Some of these have been kept out of doors since December 27, 1905, during which time they have been repeatedly frozen, and seem to be in better condition than those which have been kept indoors, inasmuch as their supply of food granules has not appreciably diminished. It is probable, therefore, that at least some embryos will survive the winter in fields grazed by infested animals during the previous season.

5. When the atmosphere becomes saturated with moisture, embryos which have reached the ensheathed stage leave the feces or earth in which they have developed and crawl up convenient objects, usually grass blades, ceasing their movements as the air becomes dry and resuming their migrations during another period of dampness.

6. When grass thus infested is eaten by a sheep, cow, goat, or some other ruminant in which *Hæmonchus contortus* is able to live, the embryos continue their development, requiring probably about three weeks to arrive at a stage when the females begin to produce eggs.

7. Owing to the fact that *Hæmonchus contortus* embryos sink to the bottom in water, it seems that stagnant pools, unless very small and shallow, are less dangerous as a direct source of infection with the parasite in question than is commonly supposed, although it is probable that more or less infection would result through the medium of such pools, since, under the influence of various disturbances in the equilibrium of the water, especially when the pool is stirred up by animals while drinking, some embryos would likely be carried to the surface, where they would be very liable to be swallowed.

Aside from the part which stagnant pools may play as a direct means of infection, they would seem in many cases to be of possibly greater

importance in an indirect manner on account of the moist earth surrounding them and, further, on account of the consequent high degree of humidity of the air in immediate contact with the moisture-laden ground. These conditions favor not only the development of the embryos to the ensheathed stage, but also thereafter their upward migrations onto the grass.

8. The general facts in the life history of *Hæmonchus contortus*, especially the mode of infection by grass upon which the embryos have crawled, will undoubtedly, in view of their nice adaptation to the peculiarities of herbivorous animals, be found to apply also to other more or less nearly related nematode parasites of herbivorous animals. As a matter of fact, it has been found that the ensheathed embryos of *Œsophagostomum columbianum* and of *Monodontus trigonocephalus* crawl up perpendicular glass surfaces in a moist atmosphere as freely as do those of *Hæmonchus contortus*, and while the extent of their resistance to cold and dryness has not yet been experimentally determined, it is not unlikely that the general facts in their life history will be found very similar to those which have been determined for *Hæmonchus contortus*.

PRACTICAL METHODS OF PREVENTION AND TREATMENT.

Without at this time entering into a lengthy discussion, a few remarks may be made in conclusion with reference to the practical application of some of the facts which have been brought out in this paper.

The high degree of resistance to freezing exhibited by the embryos shows that the cold of winter can not be depended upon to free a pasture of infection, so far as *Hæmonchus contortus* is concerned; and as to the length of time necessary for the embryos to die of starvation, that is not yet known. On the other hand, it seems safe to conclude that thorough burning of a pasture, the value of which as a preventive measure has been repeatedly demonstrated by practical experience, will serve as an adequate means of disinfection, since the tendency of the embryos of *Hæmonchus contortus* to migrate upward renders it almost certain that, under ordinary conditions, few of them will be present at a sufficient depth below the surface of the soil to escape death from the heat of burning grass.

With a means of disinfection at hand, the next question is that of freeing from parasites the animals which are to be placed upon the disinfected pasture, a very important and necessary provision, since if even a few of the animals harbored worms they would begin immediately to reinfect the pastures, and thus the healthy ones of the flock would soon suffer also. While treatment with vermifuges, though expensive and difficult to carry out on a large scale, is more or less effective in improving the condition of animals suffering with roundworms, especially *Hæmonchus contortus*, it can not be trusted to remove all of the worms.

Accordingly, the proposition to rid a flock of parasites by means of vermifuges so completely that when placed upon a clean pasture the animals will thereafter remain free from parasitic diseases may be dismissed as practically impossible. The problem may, however, be approached from another side. The prospects seem fairly good that with a little care exercised in the proper directions lambs may be raised free of parasites, at least of *Hæmonchus contortus*, and thus furnish clean stock to be placed upon clean pastures. Experiments elaborating this idea are now in progress. It should be noted here that Dalrymple, of Louisiana, has devoted considerable time to this solution of the problem and has met with some success, in the case of *Œsophagostomum columbianum* especially, notwithstanding the fact that he has been necessarily handicapped on account of the small amount of definite knowledge which was available concerning the life histories of the forms with which he was working.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *April 23, 1906.*

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